National Renewable Energy Laboratory

Enzyme Sugar Platform (ESP) Project

Project Overview

Dan Schell

FY03 Review Meeting

Golden, Colorado

May 1-2, 2003

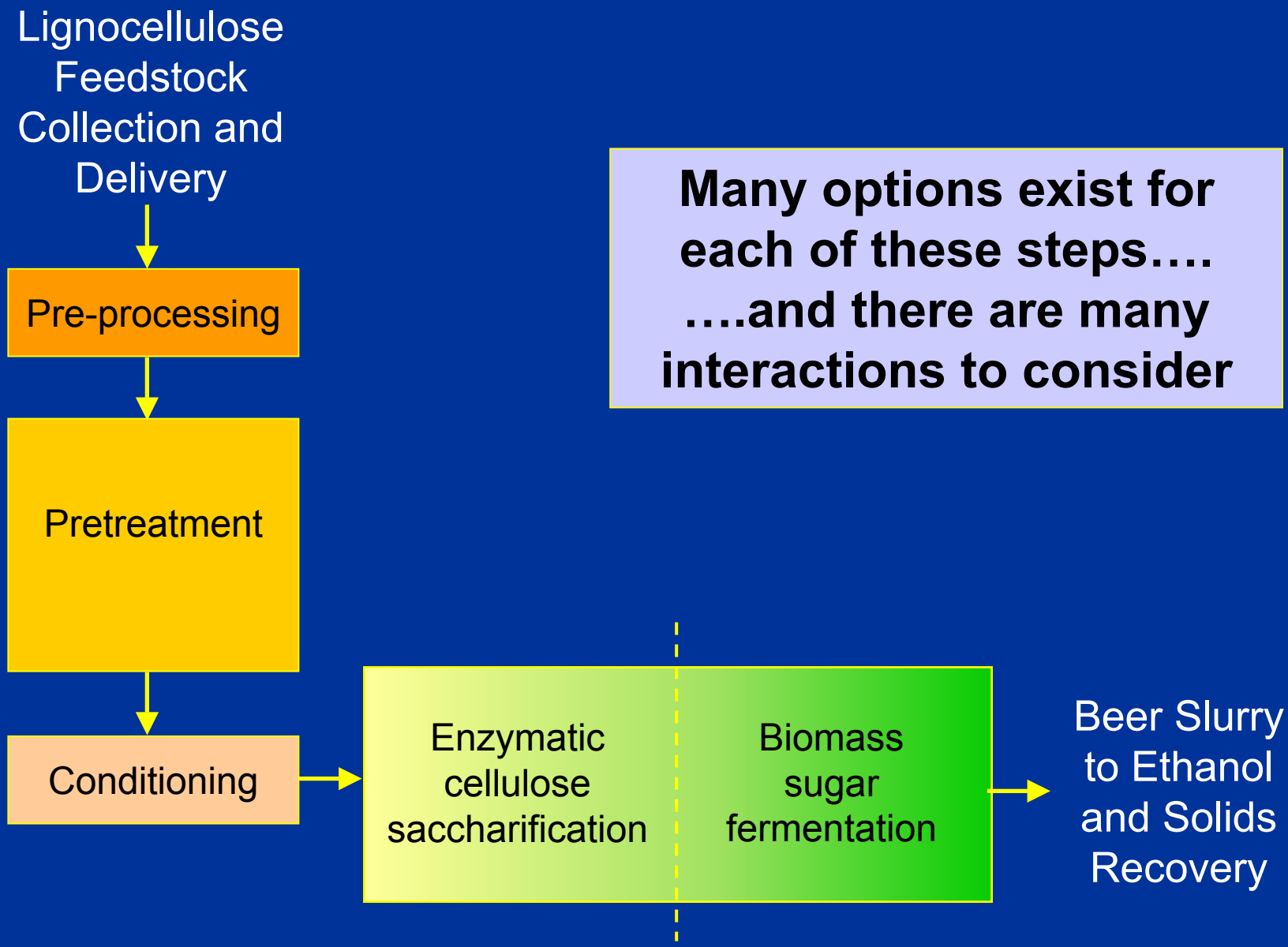
Outline

- Introduction
- History
- Meeting Goals
- Evaluation Criteria
- How Work Efforts/Presentations Address Key Barriers

High-Level Project Mission

Facilitate commercialization of enzyme-based cellulose hydrolysis “Sugar Platform” technology by advancing enabling tools and knowledge.

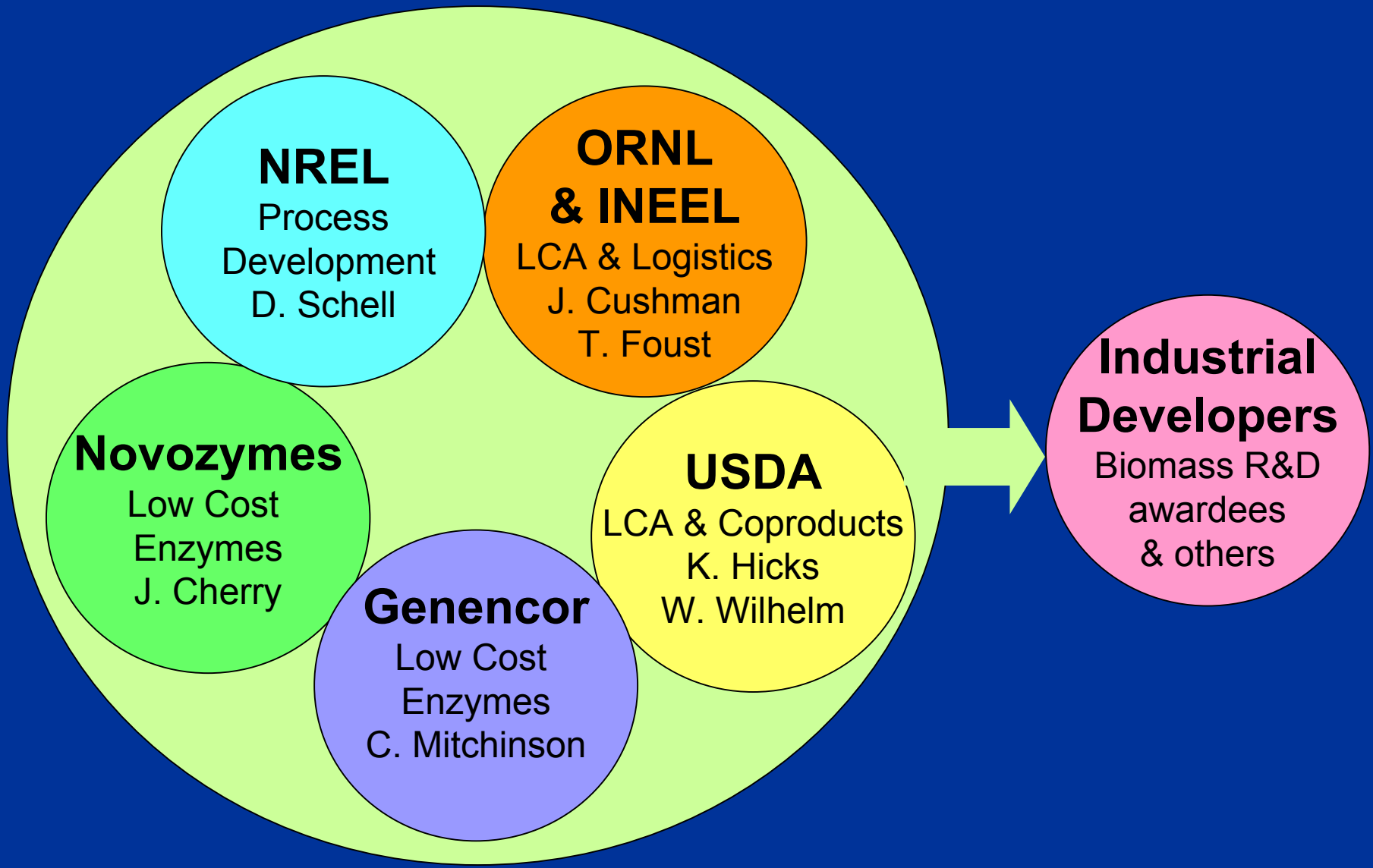
Major Steps in an Enzymatic Process



Critical Success Factors

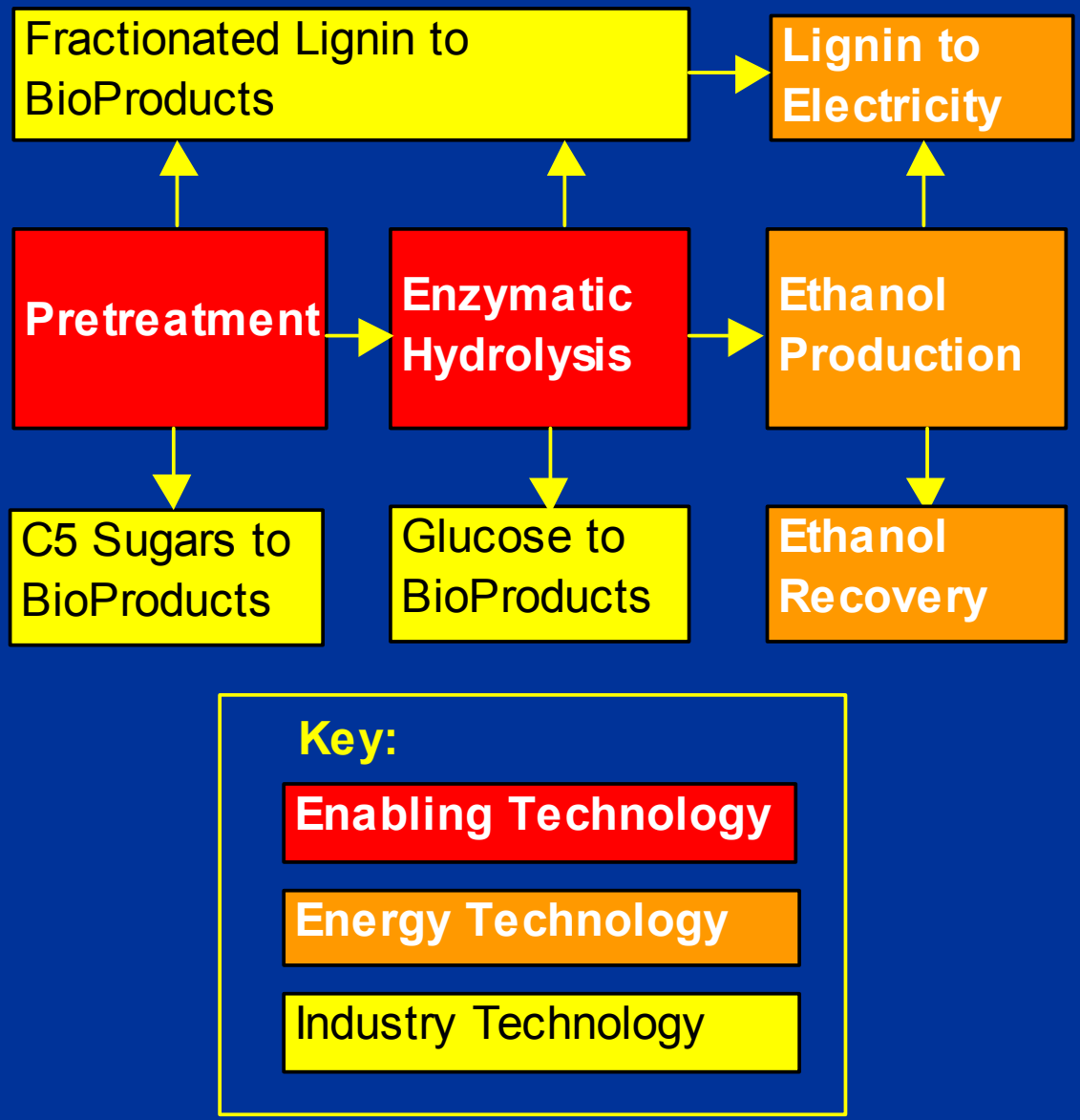
1. The integrated process must perform reliably at levels commensurate with attractive economics
   - *Focus of project work is rigorous process modeling and high-quality performance data and mass balances for integrated systems operated under realistic conditions*
2. Sufficient quantities of corn stover (or other feedstock) must be sustainably available at an acceptable cost
   - Sustainable harvest must be proven and documented; focus of life cycle assessments being supported by NREL, ORNL, USDA, and others
   - Technologies and infrastructure must be developed to collect, store, transport, and deliver feedstock; focus of ORNL, INEEL, and USDA efforts (*roadmap effort underway)*
3. Cost-effective cellulase enzymes must be available
   - Focus of DOE-subcontracted efforts by Genencor and Novozymes

Main Project Participants

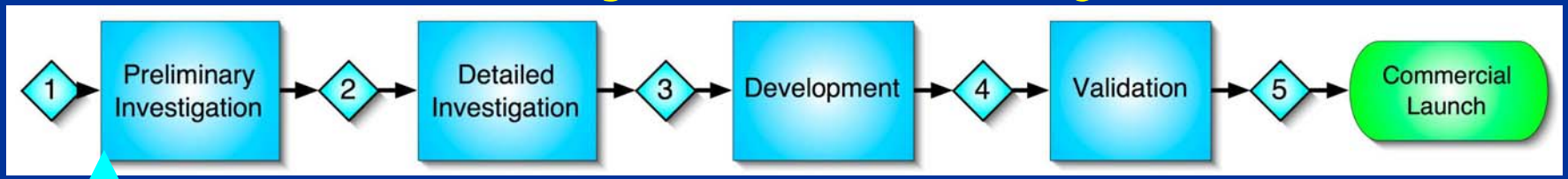


Strategic Fit: Enabling Biorefineries

- This project demonstrates enabling technology for a lignocellulose-based biorefinery
- This project focuses on the core steps needed to produce sugars, fractionated lignin, and ethanol



Project History



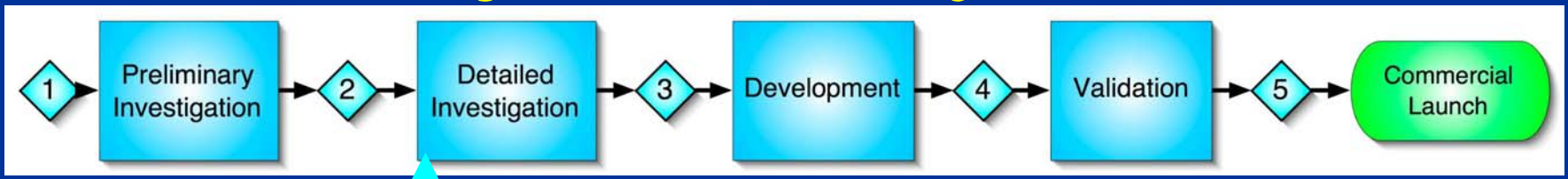
Stage 1 work initiated in 2000

(project conceived to be on commercial track as placeholder for eventual industry-led effort)

Stage 1 Highlights

- Selected corn stover as the model feedstock
- Initiated literature reviews of pretreatment and cofermentation technology
- Began outreach/discussions with key stakeholders

Project History (cont'd)



Stage 2 work started in January 2001

Stage 2 Highlights

- Developed better understanding of market opportunity
- Substantially advanced process modeling
- Finished pretreatment and fermentation literature reviews, started technology down-selection
- Began multi-institution supported life cycle analysis effort with ORNL, USDA and other laboratories

Project History (cont'd)

Passed Gate 3 in January 2002 and began Stage 3…

Today's focus

- Highlights of Gate 3 reviewer feedback and our responses
- Current work priorities
- Summary of recent accomplishments and future plans

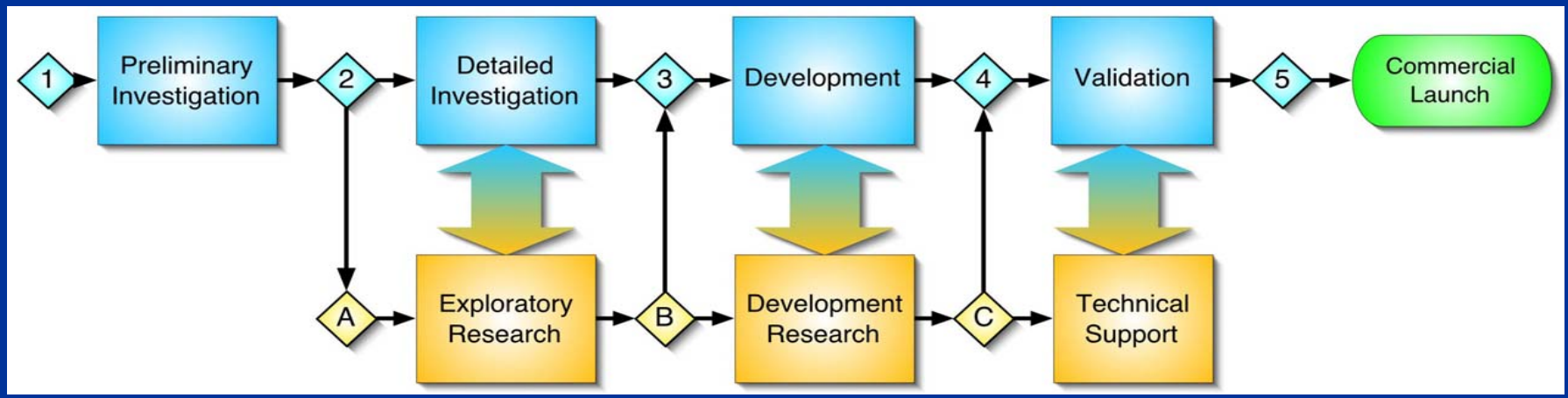
High-Level Reviewer Feedback
Gate 3 January 2002

- Focus on core saccharification technology and integration issues rather than trying to assemble a full technology package
  - Let industry select specific combinations of feedstocks, processes, and products for commercial track projects aimed at exploiting particular business opportunities

Stage Gate Project Management

Bioenergy Awards

Commercial Track Projects



Research Track Projects

ESP Project
Related Core R&D

Project Work Priorities

- Core Technology Research
  - Sample compositional analysis, feedstock variability, high solids pretreatment, enzymatic cellulose hydrolysis, and integrated processing
- Process Engineering and Analysis Research
  - Adding risk analysis to technoeconomic evaluations
  - Completing substantially improved life cycle analysis (LCA)

ESP Project Resource Allocation

Staff years

Activity	FY02 (actual)	FY03 (plan)	Delta (FY03-FY02)
Proj. management/communication	1.0	0.7	(0.3)
Process modeling and economics	2.2	1.0	(1.2)
Sample compositional analysis	1.5	0.5	(1.0)
Corn stover variability	1.4	0.7	(0.7)
Pretreatment	2.2	1.6	(0.6)
Fermentation strain evaluation	1.2	0.0	(1.2)
Enzyme hydrolysis/process integration	1.2	1.8	0.6
Total	10.7	6.3	
Other			
Life Cycle Analysis	0.25	0.25	0.0
Enzyme Testing/Evaluation	1.5	2.2	0.7

Financial Resources
(k$)

	FY02 (actual)	FY03 (plan)
Labor	1,420	1,070
Other direct cost	112	197
Subcontracts	300	130
Project Total	2,085	1,731

Purpose of Today's Meeting

- Update stakeholders on recent accomplishments
- Recommend future work directions for
  - ESP project
  - Related sugar platform activities
- Solicit feedback on recommendations (framed in context of review criteria; see next slides)
  - Are we focusing on right issues?
  - Are we appropriately facilitating commercial-track projects? (Is this known?)
- Solicit recommendations

What are the Review Criteria?

- Strategic Fit
  - Does project build knowledge, tools, or capability in alignment with Program goals?
- Customer
  - Who are the customers for this knowledge?
  - Is this information valuable to them?

Criteria (cont'd)

- Technical Feasibility and Risk
  - Is research approach feasible?
  - What are the technical risks?
- Competitive Advantage
  - Does knowledge or capability improve the likelihood of commercial success?
  - Attractive relative to other (old/new) routes?
  - What are relative chances for success?

Criteria (cont'd)

- Legal/Regulatory Compliance
  - What patent, emission, safety, and permitting issues must be considered?
  - Are they surmountable?
- Critical Success Factors and Showstoppers
  - What are the major technical and market/financial barriers?

Many Technical & Market Barriers

Enzyme-Based Process

Feedstock

- Infrastructure – collection, transportation, handling, storage
- Composition – validated methods and sensors
- Variability
- Sustainability

Pretreatment/ Conditioning

- Process chemistry
- Role of biomass structure and composition
- Materials of construction
- High solids processing

Enzymatic Hydrolysis

- Low specific activity
- High cost
- Biomass structure and composition influence on reactivity
- Fundamental enzyme biochemistry

Sugar Fermentation

- Fermentation microorganisms
- Bio/catalysts

Process Integration

- High quality performance data
- Understanding of key process interactions
- Separation requirements
- Kinetic models

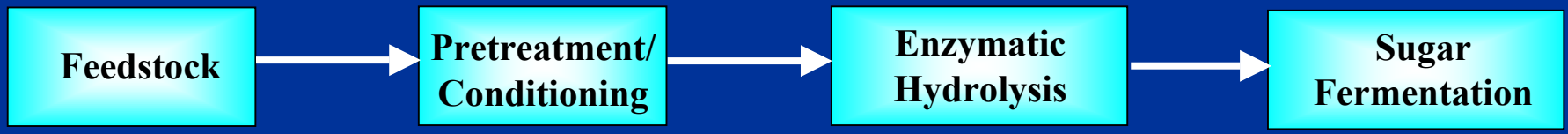
Other

- Lignin Utilization

Legal/Regulatory: safety, emissions, greenhouse gases, permitting, waste disposal

Financial: high cost and risk, market, policy and funding uncertainties

Today's Presentations



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Process Integration

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Process Modeling and Economics

Evaluates technical feasibility, risk, and competitiveness, and guides R&D priorities

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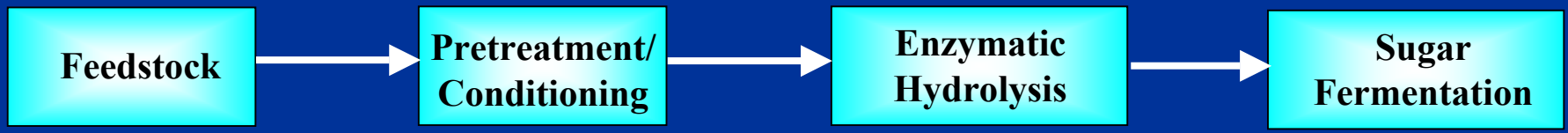

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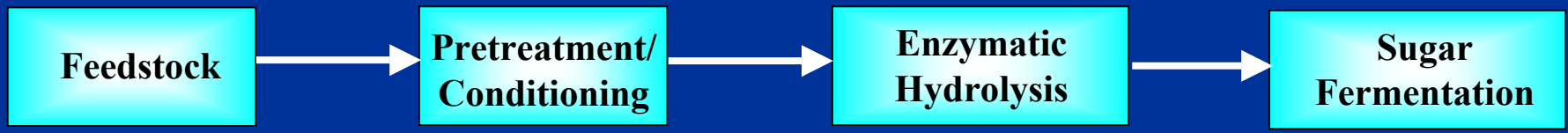

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<u>Process Integration</u>

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High Solids Pretreatment

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<u>Other</u>

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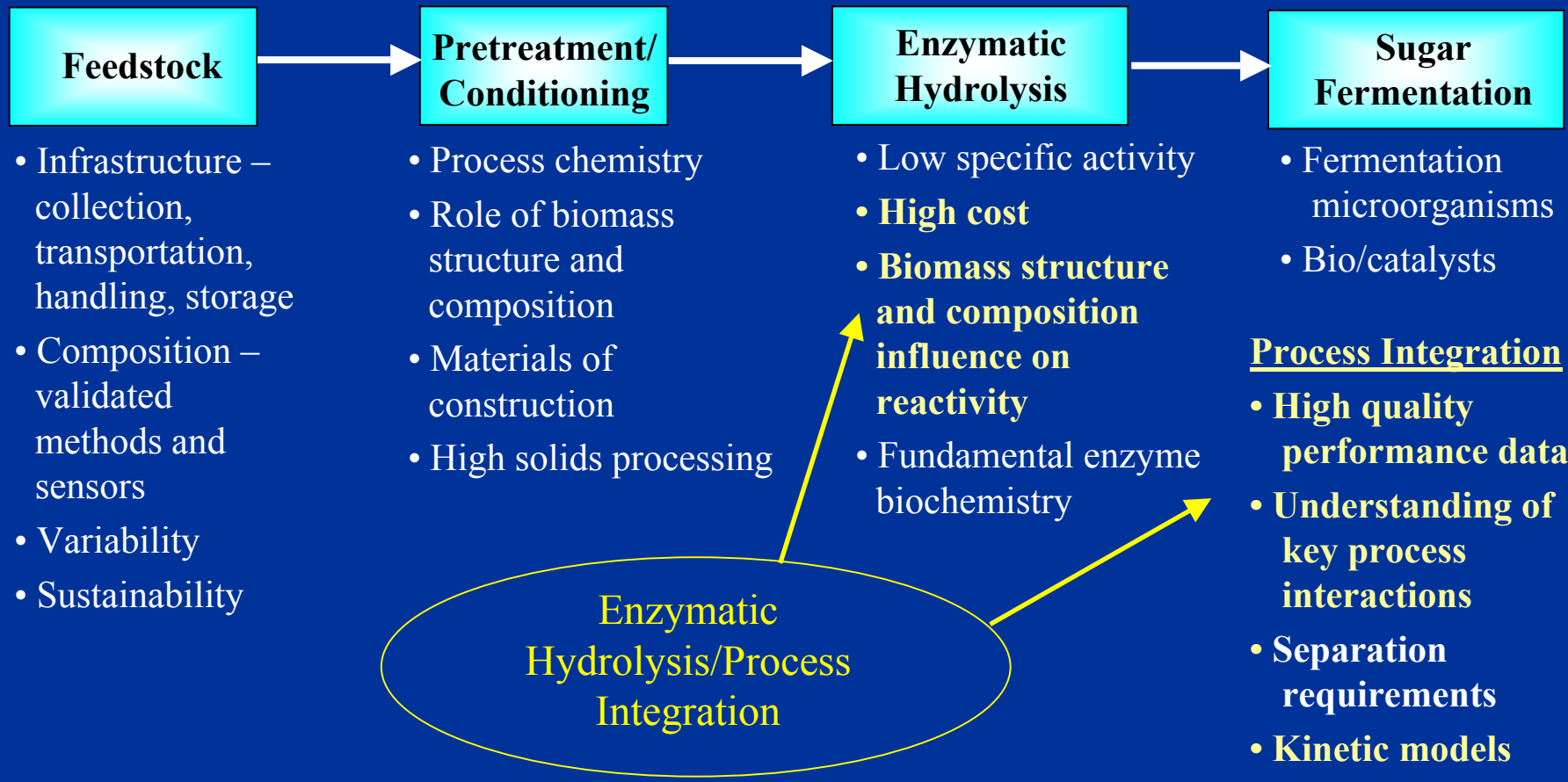

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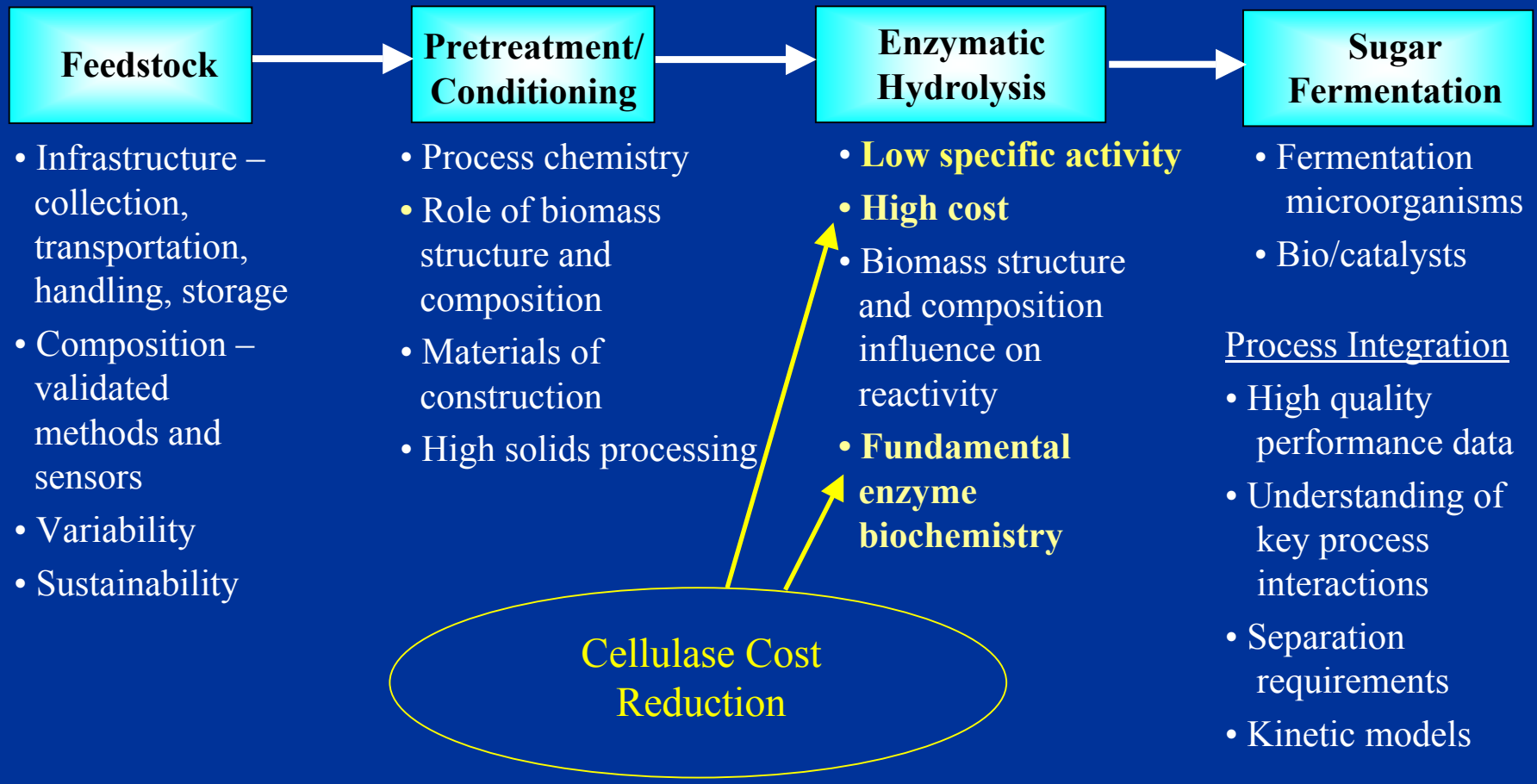
- **Lignin Utilization**

Tomorrow's Presentations



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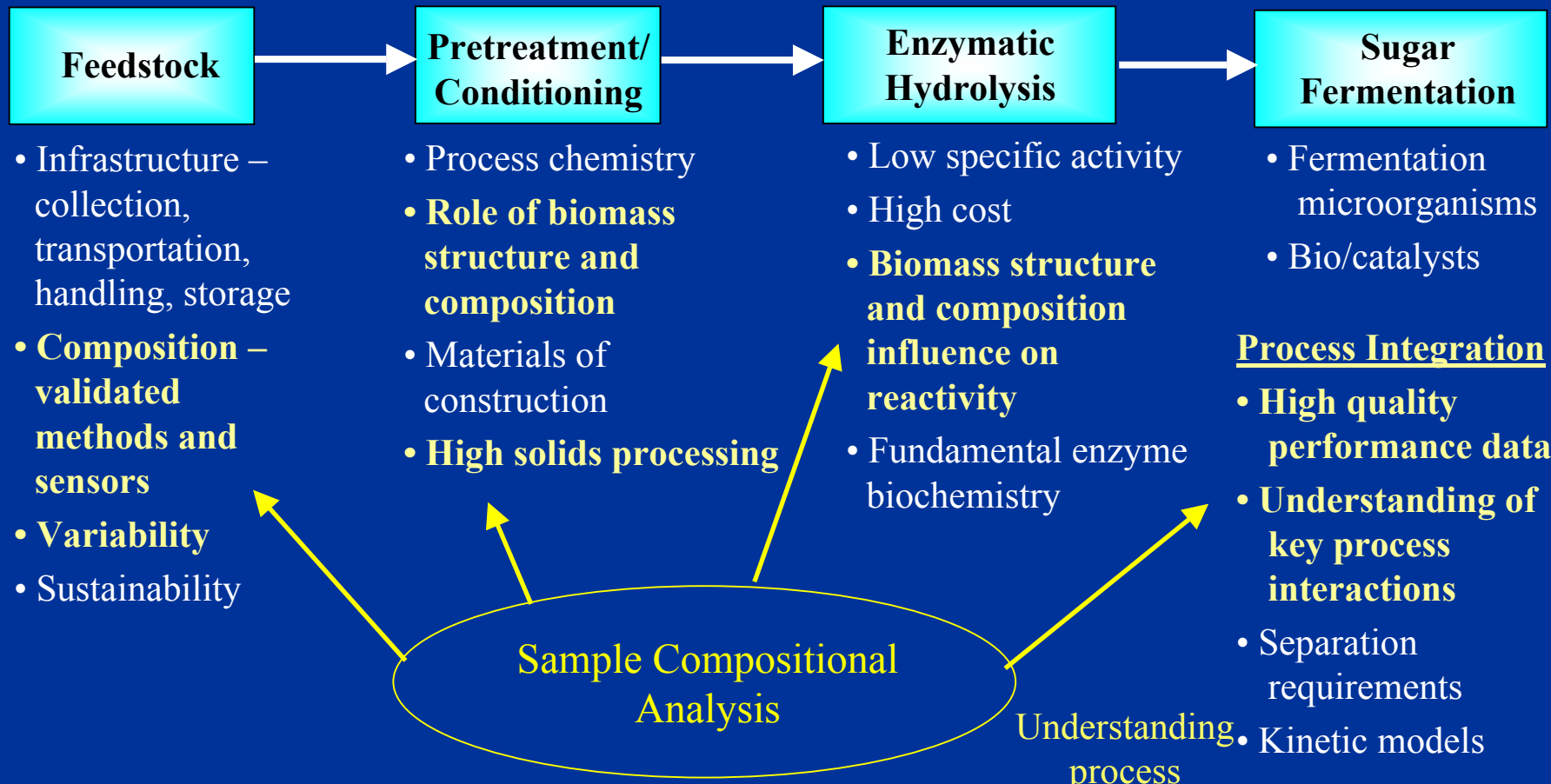

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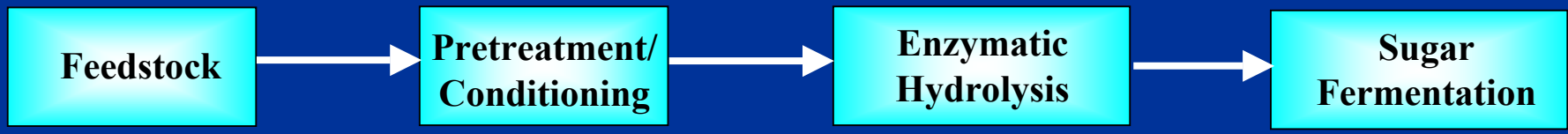

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Process Integration

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Partnerships

Focus on old and new customers

Legal/Regulatory: safety, emissions, greenhouse gases, permitting, waste disposal

Financial: high cost and risk, market, policy and funding uncertainties

Other

- Lignin Utilization

ESP Project Review Agenda

- Project Overview (Dan Schell)
- Analysis Progress
  - » Process Modeling and Economics (Mark Ruth)
  - » Life Cycle Analysis (Cindy Riley)
- Experimental Progress
  - » Corn Stover Variability (Steve Thomas)
  - » Pretreatment (Dan Schell)
  - » Enzymatic Hydrolysis/Process Integration (Kiran Kadam)
- Summary/Next Steps (Dan Schell)